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Macklin, Mark; Lewin, John; Jones, Anna Frances

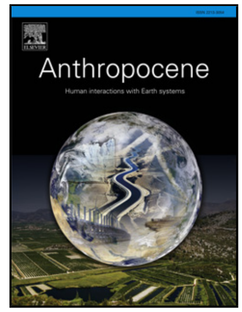
Published in:
Anthropocene

DOI:
10.1016/j.ancene.2014.03.003

Publication date:
2014

Citation for published version (APA):
Macklin, M., Lewin, J., & Jones, A. F. (2014). Anthropogenic alluvium: An evidence-based meta-analysis for the UK Holocene. *Anthropocene*, *6*, 26-38. https://doi.org/10.1016/j.ancene.2014.03.003

Accepted Manuscript



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Author: M.G. Macklin J. Lewin A.F. Jones

PII: S2213-3054(14)00012-5
DOI: http://dx.doi.org/doi:10.1016/j.ancene.2014.03.003
Reference: ANCENE 33

To appear in:

Received date: 30-10-2013
Revised date: 12-3-2014
Accepted date: 24-3-2014

Anthropogenic alluvium: an evidence-based meta-analysis for the UK Holocene

M.G. Macklin[ab*], J. Lewin[a] and A.F.Jones[c]

[a] Centre for Catchment and Coastal Research and the River Basin Dynamics and Hydrology Research Group, Department of Geography and Earth Sciences, Aberystwyth University, Ceredigion SY23 3DB, UK
[b] Innovative River Solutions, Institute of Agriculture and Environment, Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand
[c] School of Geography, Planning and Environmental Policy, University College Dublin, E001 Newman Building, Belfield, Dublin 4, Ireland

*Corresponding author: email – mvm@aber.ac.uk

Abstract
An exploratory meta-analysis of ^{14}C-dated Holocene anthropogenic alluvium (AA) in the UK is presented. AA units were categorized by grain size, catchment area and location, depositional environment, and according to diagnostic criteria linked to recorded types of anthropogenic activity. The oldest AA units date to the Early Bronze Age (c. 4400 cal. BP) and there is an apparent 1500 year lag between the adoption of agriculture (c. 6000 cal. BP) in the UK and any impact on floodplain sedimentation. The earliest influence of farming on UK rivers appears to have been hydrological rather than sedimentological. The medieval period was characterised by accelerated sedimentation of fine-grained AA, notably in the smallest catchments. There are some apparent regional differences in the timing of AA formation with earlier prehistoric dates in central and southern parts of the UK.

Keywords: Anthropogenic alluvium, human impact, floodplains, rivers

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1. Introduction

In processing the impacts of human activity (which may be regarded as *allogenic*, different from but comparable to the effects of climatic or tectonic transformations), alluvial systems have their own temporal and spatial patterns of *autogenic* activity. Anthropogenically-related changes in discharge or sediment supply are routed through catchment systems, which then adjust their morphology and internal sediment storages (Macklin and Lewin, 2008). For deposition, there is a process hierarchy involved: small-scale strata sets representing individual events (laminae for fine sediment), evolving form units (e.g. point bars or levees), architectural ensembles (such as those associated with meandering or anastomosing rivers) and alluvial complexes involving whole river basin sequences. Anthropogenic alluvium (AA) may be seen at one level as simply an extra ‘blanket’ to a naturally formed channel and floodplain system; at another it is a complex of supplements and subtractions to an already complicated sediment transfer and storage system. AA may alternatively be known as post-settlement alluvium (PSA), although that term is generally applied to any sedimentation that occurs after an initial settlement date, however it was generated (cf. Happ et al., 1940). PSA also forms a sub-category of legacy sediment (LS) derived from human activity (James, 2013), which includes colluvial, estuarine and marine deposits. AA may comprise waste particles derived from industrial, mining and urban sources (e.g. Hudson-Edwards et al., 1999) or, more generally, a mixture with ‘natural’ erosion products. Accelerated soil erosion resulting from deforestation and farming also introduce sediment of distinctive volume as well as character.

For sediment transfers, UK tracer studies of bed material demonstrate a local scale of channel and floodplain movement from cut bank to the next available depositional site (Thorne and Lewin, 1979; Brewer and Lewin, 1998). However, vertical scour in extreme events without lateral transfer is also possible (Newson and Macklin, 1990). *Fine* sediment behaves rather differently: long-distance transfers in single events, temporary channel storage in low-flow conditions, but longer-term storage inputs highly dependent on out-of-channel flows. In these circumstances, considerable care has to be exercised when interpreting AA transfer and accumulation, and especially in using combined data sets for depositional units that have been processed to arrive on site over different timespans. Fine sediment is most likely to be dispersed catchment-wide during major floods, whilst alluvial sediment stored down-catchment may also be locally re-eroded and re-deposited by the same event.

'Connectivity' has been a major theme in UK fluvial research in recent years, particularly in empirical contexts of coarse sediment transfer in upland environments involving gully, fan and adjacent floodplain (Harvey, 1997; Hooke, 2003), and in the transfer of sediment within valleys in the form of sediment slugs or waves (Macklin and Lewin, 1989; Nicholas et al., 1995). These and studies elsewhere have commonly used morphological estimates and budgeting of sediment flux, both from historical survey comparisons (decades to centuries) and from reconnaissance assessments of apparently active erosion or sedimentation sites. On the longer timescale necessary for assessing human impact, whole-catchment modelling involving Holocene sediment routing has also demonstrated how complex and catchment specific these internal transfers may be in response to climatic and land cover changes (Coulthard et al., 2002; 2005). Major elements of UK catchment relief involve variable lithologies, over-steepened to low-gradient slopes, rock steps, alluvial basins, and valley fills inherited from prior Pleistocene glacial and periglacial systems (Macklin and Lewin, 1986). Some of these locally provide what may be called 'memory-rich' process environments. Progressive and ongoing Holocene evacuation of coarse Pleistocene valley fills is of major significance in a UK context (Passmore and Macklin, 2001), and this differs from some of the erodible loess terrains in which many other AA studies have been conducted in Europe and North America (e.g. Trimble, 1983; 1999; Lang et al., 2003; Knox, 2006; Houben, 2008; Hoffmann et al., 2008; Houben et al., 2012).

Human activities have greatly modified hydrological systems, and in different ways: in terms of discharge response to precipitation and extreme events, but also in the supply of sediment. For finer sediments (where sediment loadings are generally supply-limited rather than competence-limited), dominant yield events (near bankfull) and sediment-depositing events (overbank) may not be the same. Holocene flood episodes (Macklin et al., 2010) may also be characterized by river incision (Macklin et al., 2013) as well as by the development of thick depositional sequences (Jones et al., 2012), depending on river environment. Fine sediment may be derived from surface soil removal, through enhanced gullying and headwater channel incision, from reactivation of riparian storages, or through the direct human injection or extraction of material involving toxic waste or gravel mining. For a millennium and more, channel-way engineering has also transformed systems to provide domestic and industrial water supply, water power for milling, improved passage both along and across rivers, fisheries improvement, and for flood protection (Lewin. 2010; 2013). These very often retard rather than enhance downstream sediment delivery. The range of anthropogenic impacts is perhaps even more various than the sedimentation systems with which they are involved.

In this paper we set out to analyse the extent of enhanced deposition of material in floodplain environments following human activity, largely through the meta-analysis of a UK data set of Holocene ^{14}C-dated alluvial units. We caution that sedimentation quantities relate both to supply factors (enhanced delivery from deforested or agricultural land, accelerated channel erosion, or as fine waste from other activity), to transportation-event magnitudes and frequency, to sedimentation opportunity (available sub-aqueous accommodation space), and to preservation from reworking (Lewin and Macklin, 2003). None of these has been constant spatially, or over later Holocene times when human impact on river catchments has been more significant and widespread.

The word ‘enhanced’ also begs a number of questions, in particular concerning what the quantity of fine alluvial deposition ‘ought’ to be in the absence of human activity in the evolving history of later Holocene sediment delivery. In the UK, there is not always a pronounced AA non-conformity, definable perhaps in colour or textural terms, as in some other more recently anthropogenically-transformed alluvial environments, most notably in North America and Australasia. The non-anthropogenic trajectories of previous late-interglacial or early Holocene sedimentation, which might provide useful comparisons, are only known in very general terms (Gibbard and Lewin, 2002). Supplied alluvial material may be ‘fingerprinted’ mineralogically in terms of geological source, pedogenic components or pollutant content (e.g. Walling et al., 1993, Walling and Woodward, 1992; 1995; Macklin et al., 2006). These records may be dated, for example, by the inclusion of ‘anthropogenic’ elements from mining waste that can be related to ore production data (Foulds et al., 2013).

We suggest that consideration of sediment routing and depositional opportunity is of considerable importance in interpreting the context of AA deposition. For example, early Holocene re-working of Pleistocene sediment is likely to have been catchment-wide, though with differential effect: limited surface erosion on slopes, gullying and fan formation on steep valley sides, active channel incision and reworking in mid-catchment locations, and the deposition of winnowed fines down-catchment. However, by the end of the later medieval period circumstances were very different, with soil erosion from agricultural land fed through terraced valley systems to produce very large depositional thicknesses in lower catchment areas where overbank opportunities were still available. Field boundaries, tracks and ditches greatly affected sediment transfers (Houben, 2008). Channel entrenchment within the last millennium (Macklin et al., 2013) has also altered the sedimentation opportunity for fine materials. In other periods or situations *without* entrenchment, floodplain fine-sediment sequestration even in upper catchment reaches may have been considerable. Alternative scenarios were created by other activities, for example with mining wastes fed directly out onto steepland valley floors, or fine sediment being retained by regulating ponds, reservoirs and weirs. At the present day local valley-floor recycling in steeper higher-energy valleys seems to be dominant, setting a maximum age for overbank fines on top of lateral accretion surfaces or within abandoned channels (the latter also accreting greater thicknesses of material in ponding situations). Lowland floodplains are dominated by moderate but variable accumulation rates (e.g., Walling et al., 1996; Rumsby, 2000). 'Supply side' factors are far from being the only factor controlling fine sediment accumulation rates at sampling sites, either locally on the variable relief of floodplains, or regionally because of entrenchment/aggradation factors.

A final qualification to be added is that to identify episodes of AA formation is not necessarily to imply that they relate simply to episodes of human activity. Climatic fluctuations have occurred in tandem, and periods of AA development may in detail relate to storm and flood periodicity (cf. Macklin et al., 2010). As has been observed many times (e.g. Macklin and Lewin, 1993), separating human and environmental effects is by no means easy, although erosion susceptibility and accelerated sediment delivery within the anthropogenic era is not in doubt.

2. Methods

Anthropogenic alluvia were identified using the latest version of the UK Holocene ^{14}C-dated fluvial database (Macklin et al., 2010; Macklin et al., 2012), containing 844 ^{14}C-dated units in total. Some studies in which dates were reported were focused on studying AA (e.g. Shotton, 1978) as defined here, but many were conducted primarily for archaeological and palaeoecological purposes. Sediment units were identified as being AA if one or more of six diagnostic criteria were noted as being present (Table 1). Of the 130 AA dated units, 66 were identified on the basis of one criterion, 53 with two criteria and 11 using three.

AA units were classified in five different ways: 1. by grain size into coarse gravels (31 units) and fine sediment (99 units in sand, silt and clay); 2. according to anthropogenic activity (deforestation, cultivation, engineering, mining, and unspecified) using associated palaeoecological, geochemical and charcoal evidence (Table 2); 3. by depositional environment (cf. Macklin and Lewin 2003, Lewin et al. 2005); 4. by catchment size; and 5. into upland glaciated (85 units) and lowland unglaciated catchments (45 units). The five depositional environments distinguished were: channel bed sediments (13 units), palaeochannel fills (49 units), floodplain sediments (60 units), floodbasins (6 units) and debris fan / colluvial sediments (2 units). Basin size was classified as <1 km^2 (26 units), 1 km^2-10 km^2 (10 units), >10 km^2-100 km^2 (21 units), >100 km^2-1000 km^2 (54 units) and > 1000 km^2 (19 units).

Radiocarbon ages were calibrated using the IntCal09 calibration curve (Reimer et al., 2009) and probabilities were summed using OxCal version 4.1 (Bronk Ramsey, 2009). To remove the effects of the variation in the gradient of the calibration curve and in alluvial unit preservation, the probability distribution for anthropogenic alluvium dates was divided by the probability distribution for all 844 dates within the radiocarbon database to give a relative probability distribution, following Hoffmann et al. (2008) and Macklin et al. (2010). The resulting probability curves were then normalised by dividing each date by the highest probability in the data set. Relative probability distributions have been plotted with the frequencies of dates in 100-year intervals, calculated using the mid-point of the 2 σ calibrated age range.

3. Results

Figure 1 shows the location of sites in the UK where Holocene fluvial units have been ^{14}C dated. AA has been identified at 93 out of 256 (36%) of these sites. This is not to say that alluviation at 163 locations has not also been affected by anthropogenic activity, but using our strict criteria this is not registered using the information reported in publications. 130 out of 844 dated UK fluvial units (15%) can be classified as AA. Anthropogenic alluvium is recorded only at one site in the Scottish Highlands and is probably under-represented in eastern England and the English Channel catchments, as well as in tidally-influenced river reaches because of the lack of ^{14}C-dated Holocene fluvial units. Only two ^{14}C-dated AA units are classified as colluvial and debris flow deposits.

The oldest AA unit is dated to c. 4400 cal. BP (Early Bronze Age) and there is an apparent 1500 year lag between the adoption of agriculture in the UK, as recorded by direct ^{14}C dating of cereal grains (Stevens and Fuller, 2012), and its impact on floodplain sedimentation (Fig. 2). There is, however, no correspondence between accelerated lake sedimentation - attributed to anthropogenic activity - (Edwards and Whittington, 2001) and AA, except at c.1000 cal. BP. Furthermore, episodes (c. 6000, 5000 and 3000 cal. BP) where lake deposition rates increase between the beginning of the Neolithic and the end of the Bronze Age, do not correspond with periods of notable cereal cultivation as identified by Stevens and Fuller (2012). Indeed, they coincide with troughs in the independently-summed probability distribution of cultivated plant food and suggest that the primary cause of accelerated sedimentation was not related to arable farming. Alternatively, climate change and/or over-grazing in these mostly small catchments in northern and western Britain and Ireland could have been contributing factors. Formation of AA in the UK begins in the Early Bronze Age, when Stevens and Fuller (2012) identify a surge in agricultural activity, although there is little relationship between the phasing of technological innovation in the prehistoric period and AA. There is however a strong correspondence between AA and the development of open field systems in the medieval period, with 53% of AA units in the UK formed within the last 1000 years (Fig. 2).

In Figure 3 AA units are plotted by UK regions, with the first appearance of AA in southeast, central, southwest and northeast England, and in central and south Wales at c. 4400-4300 cal. BP. AA in southeast, southwest, central England as well as in Wales is associated with prehistoric farming. In southwest England and Wales there was significant AA formation during the medieval and post-medieval periods. AA in southern Scotland and northwest and northern England appears to be associated with medieval land-use change.

In Figure 4 AA units are sub-divided according to catchment size where study sites are located. Most dated AA units fall either in catchments of <1 km^2 or are found in ones with drainage areas that are > 100 km^2 -1000 km^2. The smallest catchments (< 1 km^2) have no dated AA units before c. 2500 cal. BP and most occur after c.1000 cal. BP. It is also perhaps surprising how few ^{14}C-dated anthropogenic colluvial deposits there are in the UK, making it difficult to reconstruct whole-catchment sediment budgets. AA units from the larger catchments (> 100 km^2) show a greater range of dates with the earliest units dating to c. 4400 cal. BP.

Figure 5 plots AA units according to sedimentary environment. Channel beds (Fig. 5A) record earlier-dated AA, whereas AA units in palaeochannels (Fig. 5B), on floodplains (Fig. 5C) and in floodbasins (Fig. 5D) increase in frequency from c.4000 cal. BP, and especially in the medieval period. One possible explanation for the early channel bed AA units is that channel erosion or gullying was contributing more sediment than erosion of soil, and that this was a reflection of a hydrological rather than a sediment-supply response to human activities (cf. Robinson and Lambrick, 1984).

The earliest coarse AA unit in the UK uplands is dated to c. 2600 cal. BP (Fig. 6) with 73% of gravel-rich AA formed in the last 1000 years, and a prominent peak at c. 800-900 cal. BP. Fine-grained AA units in upland catchments have a similar age distribution to their coarser counterparts, and 80% date to the last 1300 years. By contrast, AA units in lowland UK catchments, outside of the last glacial limits, are entirely fine-grained and were predominantly (69%) formed before 2000 cal. BP, especially in the Early Bronze Age and during the Late Bronze Age/Early Iron Age transition c. 2700-2900 cal. BP.

Figure 7 plots relative probability of UK AA classified according to their association with deforestation, cultivation and mining. The age distributions of AA units attributed to deforestation and cultivation are similar with peaks in the later Iron Age (c.2200 cal. BP). Deforestation is also associated with a later AA peak in the medieval period, whilst AA units related to mining activity date mostly to post-medieval times.

4. Discussion

The evidence presented above may be compared with conclusions that have been drawn from studies elsewhere, although regional and local site conditions vary a great deal. Considerable colluvial storage of eroded soil materials has been suggested, particularly in the loess terrains of southern Germany (Bork, 1989; Lang, 2003; Houben, 2003; 2012; Dotterweich, 2008) and Belgium (Broothaerts et al., 2013); from the much later phase of cultivation in North America (Happ et al., 1940; Walter and Merritts, 2008); but also from prehistoric site studies in the UK (Bell, 1982; Brown and Barber, 1985; Brown, 1987). On the other hand, French et al. (2005) suggest that in UK chalkland areas early soil erosion and thick colluvial deposits may have been less than previously supposed. Stevens and Fuller (2012), following an analysis of radiocarbon dates for wild and cultivated plant foods, suggest that an agricultural revolution took place in the UK during the Early-Middle Bronze Age. This shift, from long-fallow cultivation to short-fallow with fixed plots and field systems, fits well with the timing of accelerated floodplain deposition identified in this study, and with the apparent lag between the development of agriculture in the Neolithic and accelerated sedimentation described elsewhere (Houben et al. 2012). However, dated AA deposits, rather than a whole catchment sediment budget, have been analysed here so that the question of whether there actually was lagged remobilization of early colluvial sedimentation, or whether early colluvial deposition was not that extensive in the first place, cannot be answered using our data. Our data set does, however, emphasize the importance of medieval erosion as noted in the UK (Macklin et al., 2010) and elsewhere in Europe (Dotterweich, 2008; Houben et al., 2012).

We also draw attention to the variable autogenic conditions involved in alluvial sequestration of AA: catchment size, depositional environments, and the grain sizes involved. Anthropogenic impact and sediment supply are commonly discussed in terms of hillslope soil erosion parameters, but channel erosion by network extension and by lateral/vertical erosion were also important sediment sources for later re-deposition. In the Holocene, sediment exchange *within* alluvial systems supplied large volumes both of coarse and fine material (cf. Passmore and Macklin, 2001; Chiverrell et al., 2010; Macklin et al., 2013), and for alluvial sedimentation hydrological factors affecting competence-limited channel erosion and network extension are as significant as the supply-limitation factors affecting the input of slope materials. There is a suggestion within our data set that such hydrological factors were important for the early entrainment and deposition of channel bed materials, whether surface soil stripping was important or otherwise (Figs. 5 and 6).

5. Conclusions

Our new evaluation of ^{14}C-dated Holocene fluvial units in the UK, using meta-analysis of a large database (844 units), suggests several interesting conclusions. A number of earlier proposals made on the nature of prehistoric and historical agricultural impacts on UK river catchments based on qualitative or individual-site observations can be evaluated using this quantitative evidence from a country-wide database. The oldest AA units in the UK date to the Early Bronze Age (c. 4400 cal. BP) and there is an apparent 1500 year lag between the adoption of agriculture (c. 6000 cal. BP) in the UK and any impact on floodplain sedimentation. The earliest environmental human impacts on river channel and floodplain systems in the UK may have been hydrological rather sedimentological. The medieval period is confirmed as an important one for the accelerated sedimentation of fine-grained materials, notably in the smallest catchments. There are some apparent regional differences in the timing of AA formation with earlier prehistoric dates in central and southern parts of the UK. Finally, the approach and criteria we use here for identifying AA could be readily applied in any river environment where fluvial units have radiometric dating control. This would enable both the spatial and temporal dynamics of agricultural sediment signals in catchments to be better understood and modelled than they are at present.

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Figure 1. UK sample sites for anthropogenic alluvium showing also the southern limit of Late Devensian glaciation and major catchments.

Figure 2. Relative probability plot of UK anthropogenic alluvium showing also the principal technological agricultural developments, summed probability distributions of direct ^{14}C dates on cultigens in the British Isles (Stevens and Fuller, 2012) from the Neolithic until the end of the Bronze Age (2650 cal. BP) and periods of accelerated lake sedimentation in Britain and Ireland (Edwards and Whittington, 2001).

Figure 3. Relative probability plot of anthropogenic alluvium subdivided by UK regions. Timings for the use of the scratch plough (A), the adoption of iron technology (IT) and the development of extensive open field systems (OFS) are indicated.

Figure 4. Relative probability plot of UK anthropogenic alluvium plotted by catchment size.

Figure 5. Relative probability plot of UK anthropogenic alluvium classified by depositional environment.

Figure 6. Relative probability plot of UK anthropogenic alluvium in upland (unglaciated) and lowland (unglaciated) catchments classified by sediment size.

Figure 7. Relative probability plot of UK anthropogenic alluvium classified by associated anthropogenic activity.

Table 1: Criteria for identifying UK anthropogenic alluvium

Type of evidence	Definition	No. of units	Examples
Colour change	Change in sediment colour resulting from a change in composition or provenance	22	Shotton (1978) River Severn; Hooke et al. (1990) River Dane
Stratification change	Change from massive to layered alluvium or *vice versa* depending on sedimentary context	15	Caseldine et al. (1988) River Exe; Dinn and Roseff (1992) River Lugg; Howard et al. (1999) River Wharfe; Foster et al. (2008) River Ribble; Foulds et al. (2013) River Swale
Artefacts	Includes objects made or modified by human agency (e.g. fence stakes, pottery) and waste materials (animal bones, charcoal)	10	Durham (1977) River Thames; Needham and Longley (1980) River Thames; Macklin et al. (1991) Coe Burn; Wild et al. (2001) Derwent catchment
Textural change	Abrupt change in grain size and/or organic content; change from peat to mineral sediment; rapid sedimentation	78	Tipping (1995) Kirtle Water; Tipping and Halliday (2004) River Tweed; Smith et al. (2005) River Trent
Biological evidence	Evidence from pollen, mollusca, and coleoptera for anthropogenic modification of the landscape (woodland clearance and cultivation); supported by environmental magnetism and charcoal	66	Brown and Barber (1985) River Severn; Moores et al. (1999) River Tyne; Dinnin and Brayshay (1999) River Trent; Foster et al. (2000) Slapton Lower Ley
Contaminants	Elevated concentrations of pollutants from metal mining (e.g. Pb, Sn) or industry (e.g. coal/coke fragments)	14	Passmore and Macklin (2000) River Tyne; Thorndycraft et al. (2004) River Erme

Table 2: Types of UK anthropogenic alluvium

AA type	Definition	Evidence	No. of units
1. Deforestation	AA resulting from the removal of forest cover	Pollen, mollusca and charcoal	35
2. Cultivation	AA associated with the cultivation of crops	Pollen or coleoptera	32
3. Engineering	AA associated with engineering works	Description of engineering works (e.g. embankments) at site	1
4. Mining	AA associated with mining activities	Mining pollutants	11
5. Unspecified	AA for which insufficient information is available to assign to 1-4 above	Various	63

N.B. Some dates fall into both the deforestation and cultivation categories

Table 3: Sources and data for UK anthropogenic alluvium

Catchment / site	Author	Site elevation (m)	Catchment size (km^2)	Depositional environment[1]	Anthropogenic alluvium type[2]	No. of dated units
Ewe						
1. River Docherty	Curry, 2000	175	< 1	C	1	1
Tweed						
2. Coldstream	Macklin and Passmore, unpublished	20	>1000	B	5	3
3. Hopecarton Burn	Tipping and Halliday, 1994	> 200	> 1	A, C	5	2
4. Dry Cleuch	Dunsford, 1999	245	0.085	C	5	2
5. Catcleugh	Chiverrell et al., 2007	265	< 1	C	1	1
6. Nitties Burn	Chiverrell et al., 2007	375	< 1	C	1	1
7. Red Scar	Foster et al., 2008	420	<1	C	5	1
8. Drowning Sike	Foster et al., 2008	310	<1	C	5	1
9. Muchra Burn	Foster et al., 2008	270	>1	C	5	1
Nith						
10. Wee Capel Cleuch	Chiverrell et al., 2007	220	< 1	C	1	1
11. Fording Hole Cleugh	Chiverrell et al., 2007	220	< 1	E	1	1
Eden						
12. Limy Cleuch	Chiverrell et al., 2007	255	< 1	C	1	1
13. Kirtle Water at Hotts	Tipping, 1995	100	11.5	B	1	1
14. Kirtle Water at Kirkconnel	Tipping, 1995	65	> 10	B	5	1
15. Kirtle Water at Kirtlebridge	Tipping, 1995	65	> 10	C	5	1
16. Logan Burn	Tipping, 1995	< 100	18	C	1	2
17. Debris cone in Pasture Beck Valley	Clark et al., 2007	c. 390	< 1	C	1, 5	2
Aln						
18. Coe Burn at Callaly Moor	Macklin et al., 1991	210	> 1	A	1/2, 2	2
Tyne						
19. River Rede	Moores et al., 1999	146	214	B	1/2	1
20. River North Tyne at Snabdaugh	Moores et al., 1999	c. 116	429	B	1/2	1
21. River South Tyne at Lambley	Passmore and Macklin, 2000	c. 142	276	B	4	2

22. River Tyne at Clara Vale	Macklin et al., 1992	c. 50	2000	A	1/2	1
23. River Tyne at Low Prudhoe	Macklin et al., 1992	c. 50	2000	A	4	1
Derwent						
24. Foulscar Gill	Chiverrell et al., 2007	c. 160	< 1	C	1	1
25. Seathwaite fan	Wild et al., 2001	c. 175	< 1	C	1	1
Leven						
26. Blind Tarn Moss alluvial fan	Chiverrell et al., 2007	c. 235	< 1	C	1	1
Lune						
27. Langdale Beck	Harvey et al., 1981; Chiverrell et al., 2007	c. 290	< 1	A, C	1	2
28. Thickcombs Gill	Dunsford, 1999	232	0.12	C	5	2
29. Carlingill	Chiverrell et al., 2007	c. 182	> 1	C	1	1
30. Calf Beck fan	Chiverrell et al., 2008	205	> 1	C	1	1
31. Swarth Greaves Beck fan	Chiverrell et al., 2008	c. 205	> 1	C	1	1
32. Long Rigg Gill fan	Chiverrell et al., 2008	c. 240	< 1	C	2	1
33. White Fell Gill fan	Chiverrell et al., 2008	c. 270	< 1	C	2	1
34. Valley side fan, Chapel Beck	Chiverrell et al., 2008	c. 230	< 1	C	5	1
35. Blakethwaite alluvial fan	Harvey, 1996	c. 410	< 1	C, E	5	2
Ouse						
36. Swale at Isles Bridge	Foulds, 2008	201	162	C	4	1
37. Arkle Beck at Heggs House	Foulds, 2008	225	53	C	4	1
38. Swale at Morton-on-Swale	Foulds, 2008	27	887	C	4	1
39. Wharfe at Starbotton	Howard et al., 1999	215	250	C	4	1
40. Wharfe at Kettlewell	Howard et al., 1999	199	250	C	4	1
41. Hollin Gill	Richards et al., 1987	145	> 1	B	5	1
42. Jugger Howe Beck	Richards et al., 1987	140	> 10	D	5	1
Ribble						
43. Upper Langden fan	Chiverrell et al., 2007	280	< 1	C	5	1
44. Calder near Nethertown	Foster et al., 2008	40	>100	B	5	2
Mersey						
45. River Dane	Hooke et al.,	45–65	152	A, C	2	3

	1990					
Trent						
46. Bole Ings	Dinnin and Brayshay, 1999	0	> 1000	D	1/2	1
47. Seymour Drain, Cottam	Havelock et al., 2003	3	> 1000	C	1	1
48. Barton in Fabis North	Havelock et al., 2003	27	> 1000	C	5	1
49. River Dove near Willington Quarry	Havelock et al., 2003	45	> 100	C	5	1
50. Mill Plantation	Havelock et al., 2003	72	> 100	C	2	1
51. Trent/Soar confluence	Brown et al., 2007	29	> 1000	B	5	1
52. Great Haywood	Havelock et al., 2003	40	> 100	C	2	1
53. River Bourne	Kelly and Osborne, 1964	72	> 100	B	2	1
54. Thurlaston Brook at Croft Quarry	Smith et al., 2005	67	56	B	1/2	1
Dyfi						
55. Pennal	Johnstone et al., 2002	0	475	C	5	1
56. Rhydygwiail	Johnstone, 2004	27	200	B	5	1
57. Hendreseifion	Johnstone, 2004	12	350	B	5	2
58. Dyfi Bridge	Rassner et al.,	2.7	>100	C	5	1
Rheidol						
59. River Rheidol	Macklin and Lewin, 1986	20	> 100	A	2	1
Tywi						
60. Abermarlais	Macklin et al., 2010	45	>100	B	5	2
Severn						
61. Arrow at Ipsley	Shotton, 1978	68	> 100	B	5	1
62. Avon at Bidford	Shotton, 1978	30	> 1000	C	5	1
63. Ripple Brook	Brown and Barber, 1985	13	> 10	C	1/2	1
64. Perry at Wyke Bridge	Brown, 1990	75	> 10	D	2	1
65. Perry at Platt Bridge	Brown, 1990	72	> 10	D	2	1
66. Perry at Fitz	Brown, 1990	56	c. 35	C	2	1
67. Red House, Caersws	Jones, 2007	116	> 100	B	2	1
68. Dolhafren, Caersws	Jones, 2007	115	> 100	B	5	2
69. Sports Ground, Caersws	Jones, 2007	121	> 100	C	4	1

70. Buttington	Macklin et al., 2002	65	> 100	B, C	5	3
71. The Roundabout	Jones et al., 2010	60	> 100	B	2	1
Wye						
72. Lugg at Wellington	Dinn and Roseff, 1992	54	750	B	5	1
73. Arrow at The Leen	Macklin et al., 2003	103	170	B	5	2
74. Arrow at Folly Farm	Macklin et al., 2003	88	200	B	5	2
75. Arrow at Ivingtonbury	Macklin et al., 2003	68	290	B	5	3
76. Lugg at Eaton Hall	Macklin et al., 2007	65	> 100	B	5	1
77. Frome at Bromyard	Brown et al., 2005	105	> 10	B	5	1
78. Frome at Bishops Frome	Brown et al., 2005	75	> 10	B	5	1
79. Frome at Yarkhill	Brown et al., 2005	56	> 100	B	5	1
80. Lugg at Mordiford Bridge	Brown et al., 2005	50	> 1000	B	5	1
Nene						
81. Nene at Wollaston	Brown et al., 1994	53	> 100	C	5	1
82. Nene at Higham Ferrers	Brown et al., 1994	38	> 100	A, C	5	3
83. Nene at Turnells Mill Lane, Wellingborough	Brown and Meadows, 1997	40	> 100	B	5	1
Thames						
84. River Windrush	Hazelden and Jarvis, 1979	77	> 100	C	5	1
85. Farmoor	Lambrick and Robinson, 1979	61	> 1000	C	2	1
86. St. Aldates	Durham, 1977	55	> 1000	C	3	1
87. Dorney	Parker et al., 2008	20	> 1000	B	2	2
88. Runnymede	Needham and Longley, 1980	14	> 1000	B	5	3
89. Kennet at West Overton	Evans et al., 1993	141	> 100	A, C	1	4
Combe Haven						
90. Combe Haven	Smyth and Jennings, 1990	2	> 10	C	1/2	5
Exe						
91. Exeter	Caseldine et al., 1988	8	> 1000	B	5	1
Slapton Ley						
92. Slapton Lower Ley	Foster et al., 2000	3	0.98	D	2	2
Erme						

93. Erme	Thorndycraft et al., 2004	7	> 10	B	4	2

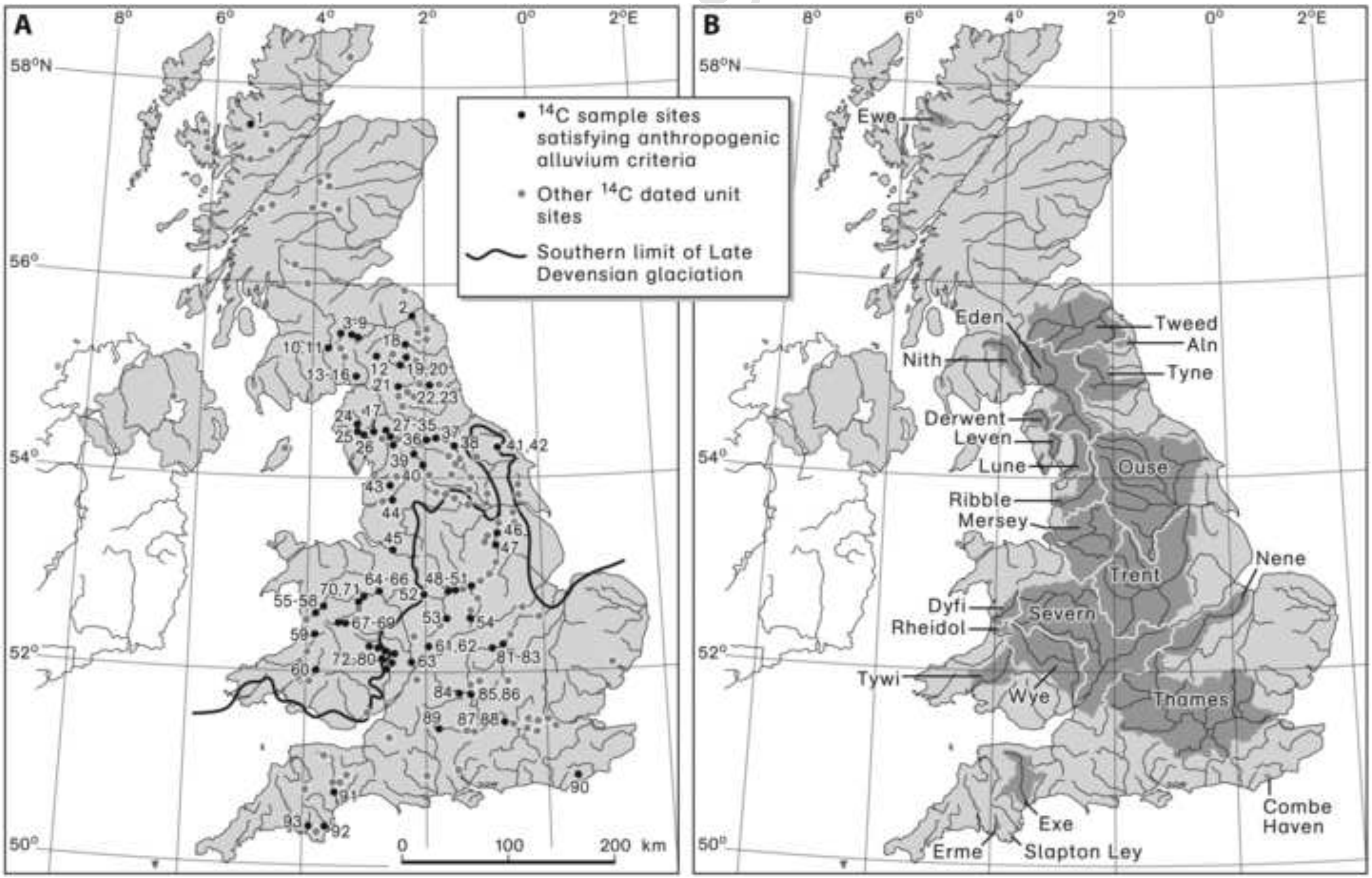
Notes

[1]Depositional environments: A channel bed, B palaeochannel fills, C floodplain sediments, D floodbasin sediments, C debris fan/colluvial sediments.

[2]Anthropogenic alluvium type: 1. deforestation, 2. cultivation, 3. engineering, 4. mining, 5. unspecified.

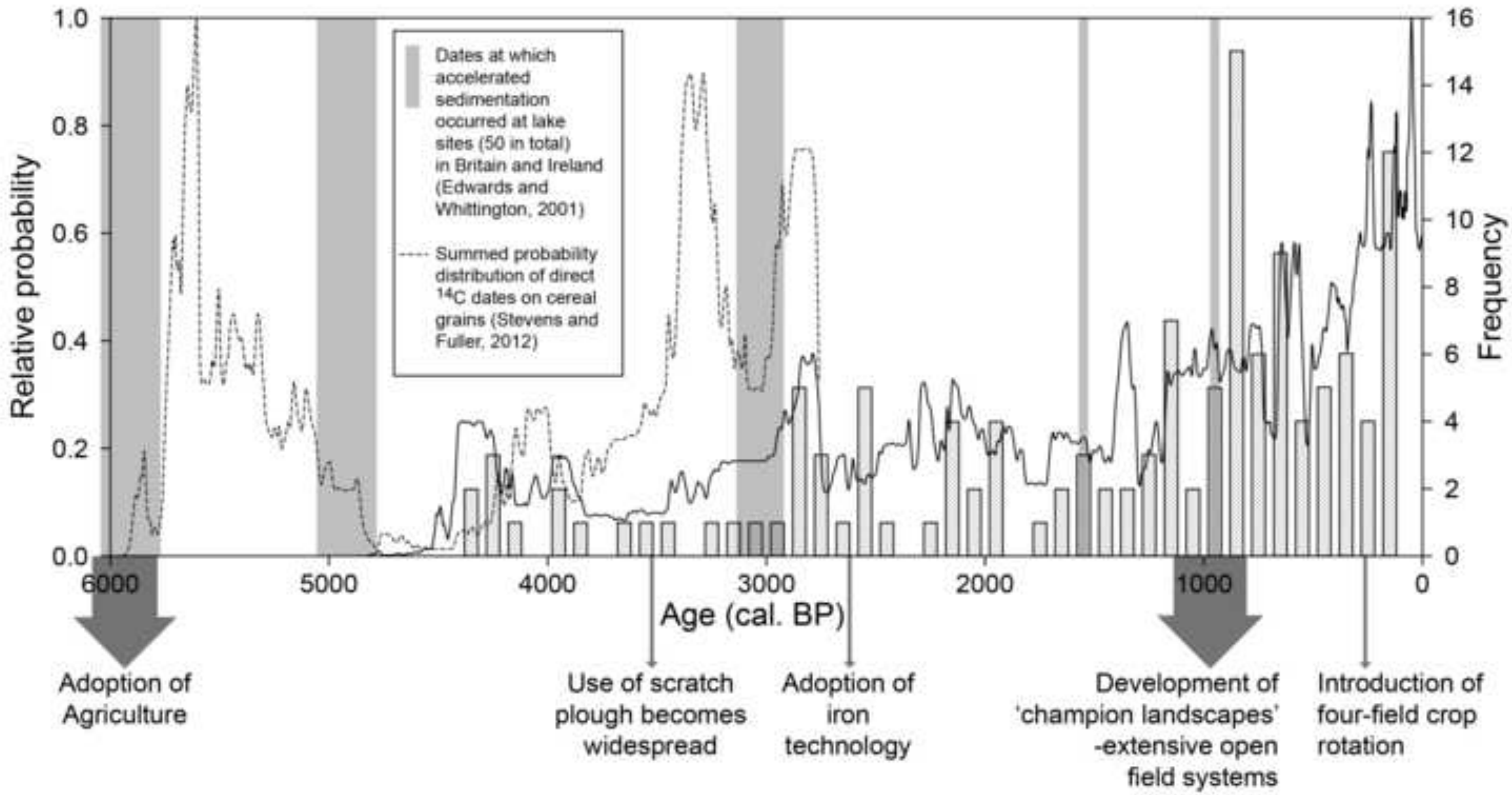
Acknowledgements
We thank the Welsh Government and the Higher Education Funding Council for Wales for funding this study through the support of the Centre for Catchment and Coastal Research at Aberystwyth University. We are also grateful to Hans Middelkoop and the three referees who reviewed our paper for their helpful comments and to the many authors who freely made available their published and unpublished ^{14}C ages listed in Table 3.

Figure

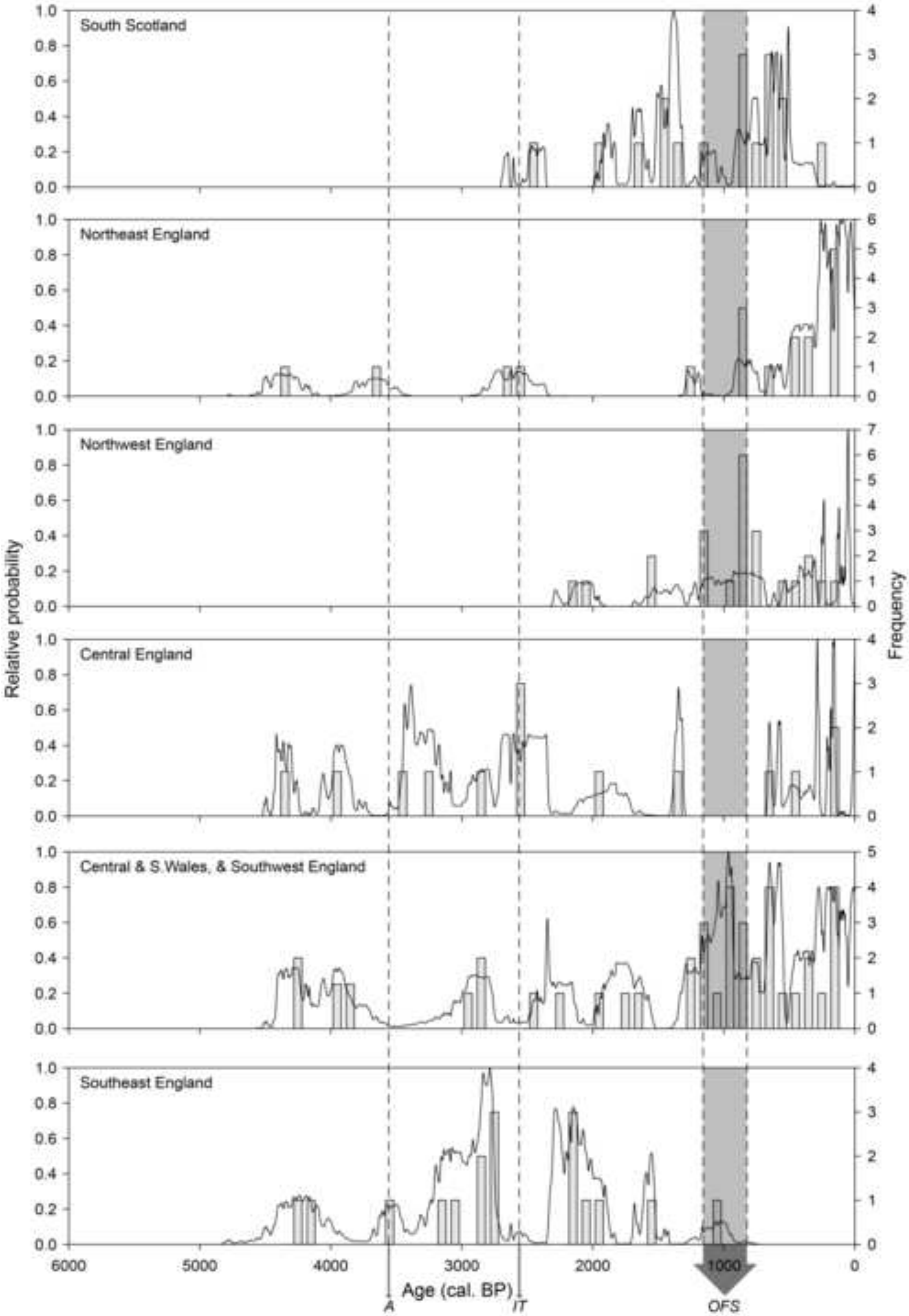


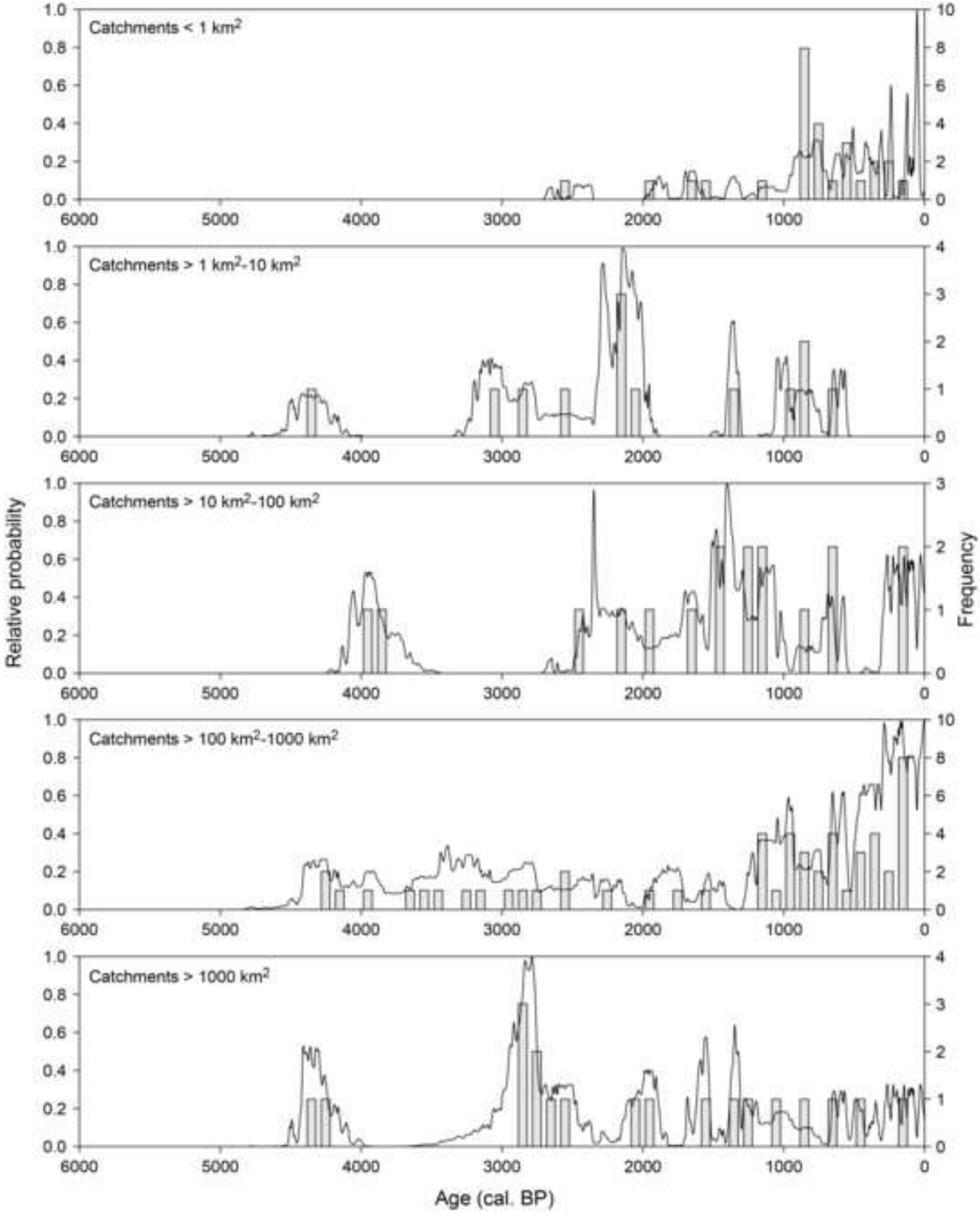
A
B
58°N
56°
54°
52°
50°
8°
6°
4°
2°
0°
2°E
^{14}C sample sites satisfying anthropogenic alluvium criteria
Other ^{14}C dated unit sites
Southern limit of Late Devensian glaciation
0
100
200 km
Ewe
Eden
Tweed
Aln
Nith
Tyne
Derwent
Leven
Lune
Ouse
Ribble
Mersey
Trent
Nene
Dyfi
Severn
Rheidol
Tywi
Wye
Thames
Exe
Erme
Slapton Ley
Combe Haven

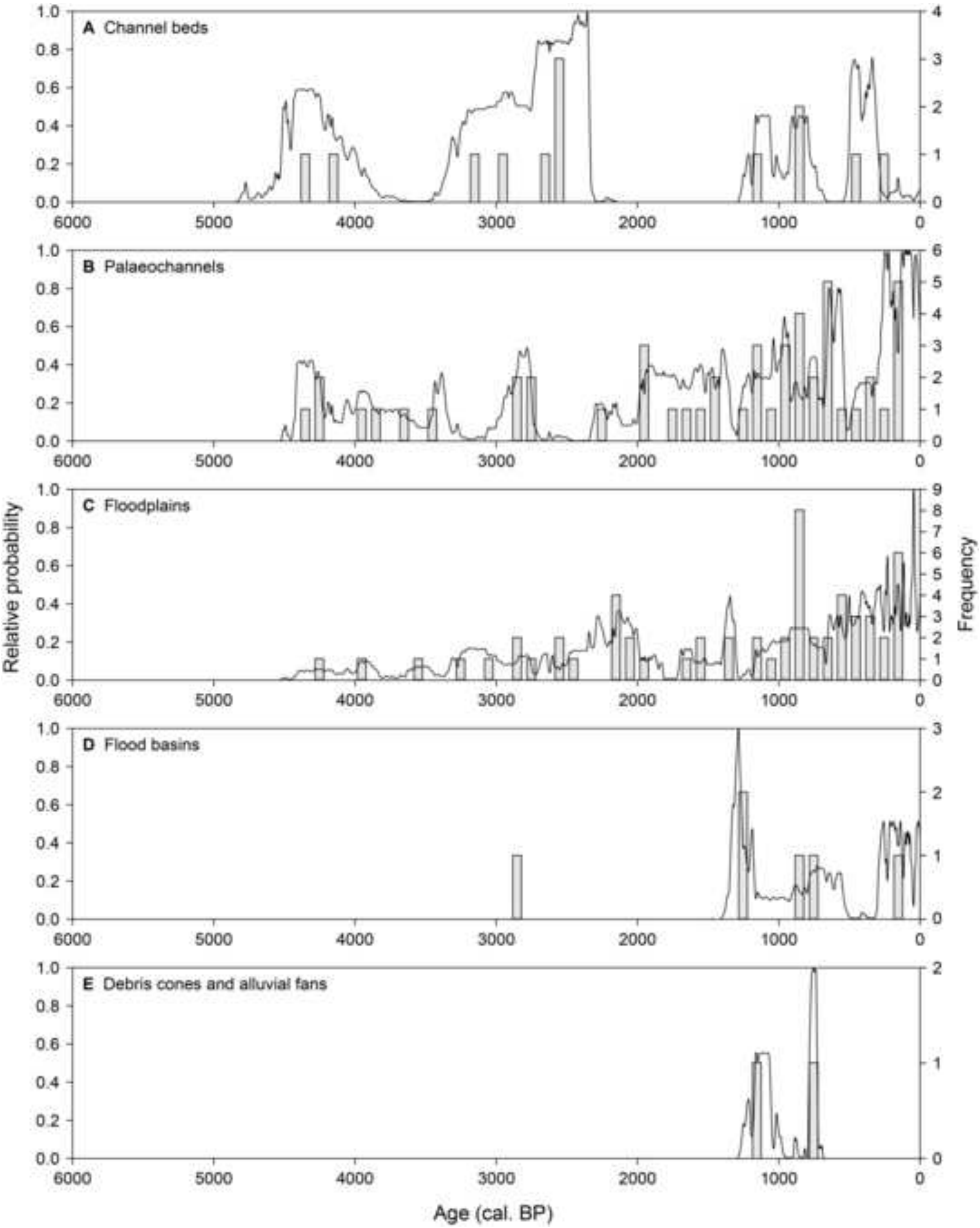
Figure

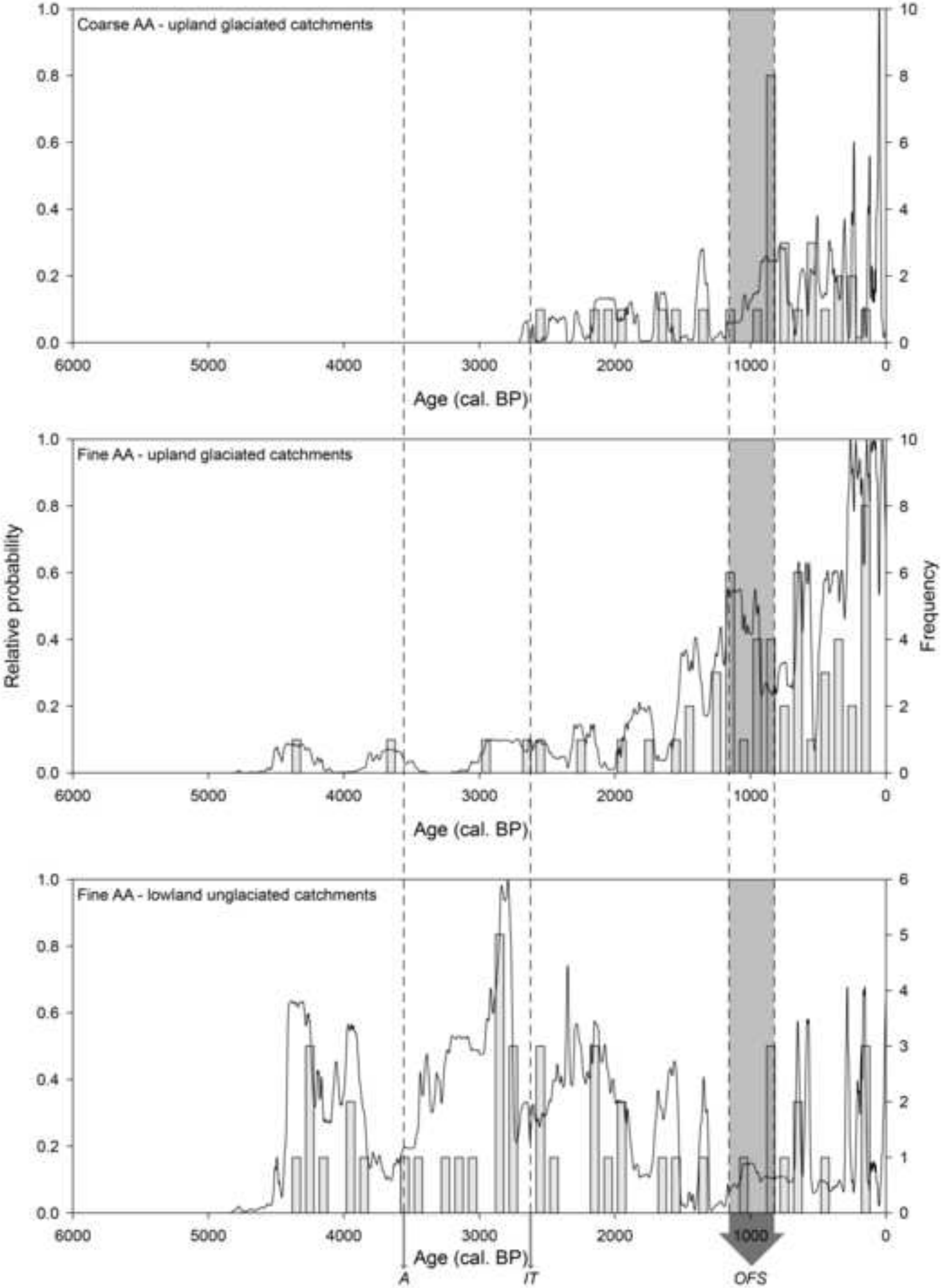


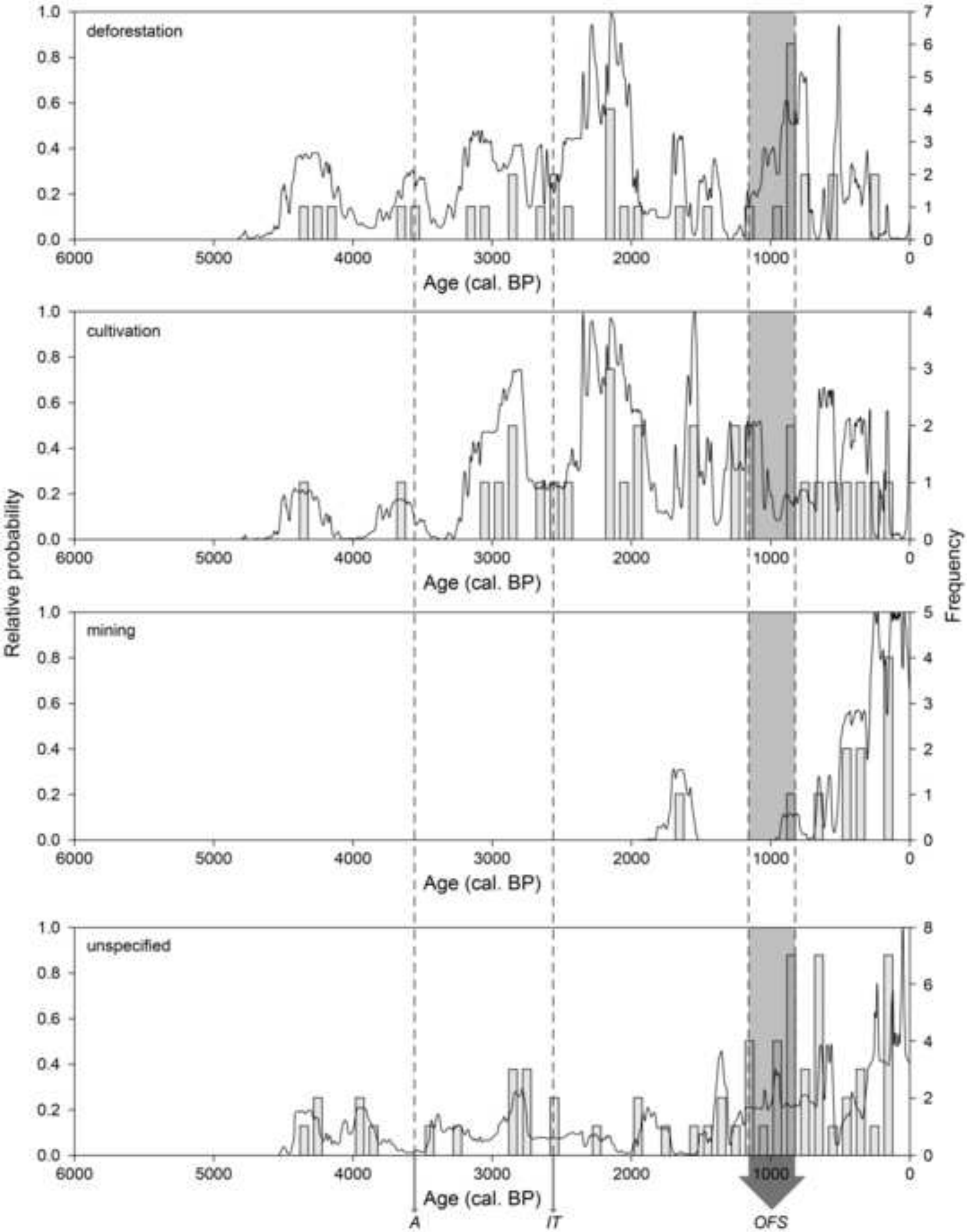
1.0
0.8
0.6
0.4
0.2
0.0
Relative probability
16
14
12
10
8
6
4
2
0
Frequency
6000
5000
4000
3000
2000
1000
0
Age (cal. BP)
Dates at which accelerated sedimentation occurred at lake sites (50 in total) in Britain and Ireland (Edwards and Whittington, 2001)
Summed probability distribution of direct 14C dates on cereal grains (Stevens and Fuller, 2012)
Adoption of Agriculture
Use of scratch plough becomes widespread
Adoption of iron technology
Development of 'champion landscapes' -extensive open field systems
Introduction of four-field crop rotation


South Scotland
Northeast England
Northwest England
Central England
Central & S.Wales, & Southwest England
Southeast England
Relative probability
Frequency
Age (cal. BP)
A
IT
OFS
6000
5000
4000
3000
2000
1000
0


Catchments < 1 km²
Catchments > 1 km²-10 km²
Catchments > 10 km²-100 km²
Catchments > 100 km²-1000 km²
Catchments > 1000 km²
Relative probability
Frequency
Age (cal. BP)


A Channel beds
B Palaeochannels
C Floodplains
D Flood basins
E Debris cones and alluvial fans
Relative probability
Frequency
Age (cal. BP)
6000
5000
4000
3000
2000
1000
0
0.0
0.2
0.4
0.6
0.8
1.0


Coarse AA - upland glaciated catchments
Fine AA - upland glaciated catchments
Fine AA - lowland unglaciated catchments
Relative probability
Frequency
Age (cal. BP)
A
IT
OFS


deforestation
cultivation
mining
unspecified
Relative probability
Frequency
Age (cal. BP)
6000
5000
4000
3000
2000
1000
0
A
IT
OFS